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STUDY #8

LARGE SCALE ICEBERG IMPACT TESTS: SITE SELECTION, HYDRAULIC TESTS AND OTHER REQUIREMENTS

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LARGE SCALE ICEBERG IMPACT TESTS:

SITE SELECTION, HYDRAULIC TESTS AND OTHER REQUIREMENTS

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ABSTRACT

Large scale sea ice impact tests have contributed significantly to ice engineering and the design of Beaufort Sea structures. No test of similar scale exists for icebergs.

This report establishes that full scale iceberg impact experiments are feasible. Such experiments would be an important advance in ice mechanics and in the prediction of iceberg impact loads on offshore structures.

The recommended site for the experiments is Deep Water Point, near St. Anthony, on the northern tip of Newfoundland. The site combines steep cliffs, deep waters, a relatively predictable iceberg population and ease of access.

The recommended experimental method is to tow an iceberg into the cliff with two tugboats. Tow ropes should be looped around on-shore pulleys installed on either side of the instrumented target. Model tests confirm this arrangement provides the best control and reliability.

1. BACKGROUND

At present iceberg impact forces are calculated using iceberg strength values based on small scale tests. Industry's latest work using indentor equipment on a grounded iceberg in Pond Inlet tested crushed areas up to three square metres (Benoit and Johnson, 1984). Experience with the loading of sea ice on arctic structures, however, indicates that the effective strength of ice is reduced as the contact area is increased. Large scale measurements performed at Hans Island and on actual structures

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have contributed significantly to ice mechanics. It is very plausible that iceberg ice would be affected in the same manner. If a large iceberg were to strike a fixed platform, the contact area of the crushed ice would be in the range of 300 to 600 square metres. The effective strength of this large contact area would probably be much lower than the results from small scale tests suggest. But before an engineering team can use this information in the design of platforms, real loads resulting from large scale iceberg failures must be measured.

2. RELATION TO ENERGY DEVELOPMENT

Iceberg impact force is one of the main design considerations for offshore structures located in the East Coast and Grand Banks area. It is critical in terms of its impact on the safety and cost of the individual structures. Up to now, accurately predicting iceberg impact force on offshore structures is one of the major uncertainties in the safe and efficient design of such structures. Therefore, this work was undertaken to establish the feasibility of large scale iceberg impact experiments with the ultimate aim of improving the estimation of iceberg impact forces.

3. SITE SELECTION

The discovery of a potential site for such experiments is one of the goals of this study. Criteria for site selection are threefold: iceberg availability, site topography and bathymetry and logistics. Twenty one possible sites were selected on the coast of Newfoundland and Labrador (Fig. 1). The best three are in the vicinity of St. Anthony, on the northern tip of Newfoundland. The recommended site is Deep Water Point. A preliminary field survey confirmed the desirability of the site: the coast is steep, with cliffs of 45 to 60 degrees extending to 60m below

water and beyond (Fig. 3, 4, 5). The town of St. Anthony provides easy accommodation and easy access to the site. The iceberg density is relatively high and stable (0.39 iceberg per 100 km^2 in June, Fig. 2). It is estimated that a search area of 23 km radius would suffice to find a suitable iceberg in June.

4. TOWING SCHEMES

Various iceberg towing methods and associated equipment were looked at. Powerful winches used in construction projects and for vessel mooring and anchored on the shore have the force and speed required to tow icebergs. The disadvantages are high cost, poor availability and difficult transportation to the site. Tractors on tracks are also a possibility. A pair of the largest in existence, D11N, could be used to advantage in this project. The disadvantage is poor availability and cost. The recommended towing method is the conventional one which uses tugboats. The advantages are crew experience, proven technology and availability. It is recommended that the tow ropes be looped through onshore pulleys so the tugs can tow seaward. Improvements in ice anchors may be necessary.

5. HYDRAULIC MODEL TESTS

A series of model tests were performed in a tow tank to compare various towing schemes in the presence or absence of alongshore currents. The recommended scheme uses two towlines attached to pulleys on either side of the impact target. With sufficient towing force and coordination between the two towboats, impacts on target can be achieved reliably. This coordination is especially crucial when a current exists. The towlines should be released about one berg length from shore. The "pendulum" concept, which uses a single pivot point upcurrent of the

target, a constant length line and the force of the current, does not work. The iceberg would hover at an angle to the cliff and not touch it. However, a modified pendulum concept works, in which the towline is pulled in, thus shortening the pivot arm during the iceberg drift. Although impacts can be generated, impacts on target cannot be assured by this method, which also requires a constant current.

Experiments were also performed in current with two towlines of unequal pull. This is essentially a combination of pendulum and winching where the line with weaker pull can be considered as the adjustable pendulum arm. This can also be considered a variation on the two equal towlines method. It worked well with experience, showing again that coordination between the towboats is essential.

6. INSTRUMENTATION REQUIREMENTS

In preliminary full scale tests instruments will be deployed that do not require accurate guidance of the iceberg for their successful use: accelerometers and strainmeters on the iceberg, high speed photography, electronic distance meter from shore, etc... In the final tests, load panels will be deployed, once accurate guidance of the colliding iceberg can be ensured.

Iceberg Motion Sensors

Four 6 degree-of-freedom motion sensor packages have been developed at C-CORE/MUN (Lever et al. 1986). These units were specifically designed to be placed on icebergs and growlers to measure their behaviour under wave action or on contact with the seabed, depending on the circumstances. Both high capacity internal data logging and telemetry options are available. The units are of rugged construction and are designed to float free when an iceberg rolls over. These sensor packages have been

successfully deployed over 30 times during the past 4 years from both helicopters and vessels, on ice masses ranging in size from a few hundred to 18 million tonnes.

One set of deployments of these instruments, during the 1985 Dynamics of Icebergs Grounding and Scouring (DIGS) experiment, captured the only full scale iceberg seabed interactions known to date, including the splitting and grounding of a multi-million tonne tabular iceberg on the Makkovik Bank (Lewis et al, 1987). The analysis of this latter event yields an estimate of the average iceberg impact pressure over an area of contact 3 orders of magnitude larger than any experiment yet conducted.

Monitoring the deformation of the ice

Even though it is probably impossible to read the stresses and strains at the failure zone, it would be interesting to embed sensors in the vicinity of the impact area in order to follow the stress distribution in the berg. The type of sensor envisaged could be of the strainmeter type or of the flat jack type. The main characteristic of the sensor which will be selected is the easiness of installation which ideally should be done remotely (dropped from an helicopter, for instance).

Instrumentation of the cliff

This is probably the most important part of the instrumentation. The first sensor candidate is a load panel similar to those used on offshore structures to monitor the ice loads (medof type). The position and the size of each of the panels are very important in order to obtain the maximum information from one impact. A combination of several panels with various areas is one of the possible patterns. If a total area of 12 m x 12 m is instrumented, the impact zone could be covered with:

* 3 6x6 panels
* 3 3x3 panels

* 3 1.5x1.5 panels
* 4 .75x.75 panels

Since these sensors usually have a slow response to the impact, it would probably be necessary to enhance the reading with a high capacity load cell which could pick up the eventual high frequency variations of the load.

Monitoring the velocity of the berg

Besides the motion sensors which will sit on the berg, a direct reading of the displacement of the berg will also be made with EDM equipment. Reflectors will be placed on the berg and followed by a time-pulsed EDM during the whole experiment. This equipment can be directly connected to a data acquisition terminal. Ideally, the monitoring of three points on the berg from three points on the shore will give the exact position of the berg at any moment.

Monitoring the towing load

In the eventuality of the berg being towed, the winches can be instrumented with load cells in order to estimate the towing force required to overcome the drag forces.

Photography and filming

The volume and the mass of the berg will be evaluated from aerial photography and underwater side scan sonar.

The impact zone will be filmed with a high speed camera in order to allow a good approximation of the contact area and to properly document the failure mechanisms.

7. RECOMMENDATIONS

This study shows that full scale iceberg impact experiments are feasible. The recommended site is Deep Water Point, near St. Anthony, Newfoundland, and the recommended method is towing by two towboats with

towlines looped around pulleys on either side of the instrumented impact target.

It is recommended that the next phase of this study be undertaken this summer. This phase includes a detailed site survey and current measurement. Detailed engineering and planning, including measurement and recording techniques should also be carried out.

The third phase would consist of equipment procurement, installation and the first season experiments. In these experiments the iceberg motions and deformations will be measured, but the cliff will not be instrumented. Thus hitting on target is not crucial.

The fourth and final phase would see the instrumentation of the cliff face and further impacts.

References

Benoit, J. and Johnson. 1984. Medium Scale Iceberg Impact Tests. Videotape shown at Arctic Offshore Technology Conference, Calgary.

Lever, J.H., Klein, K. and Diemand, D. 1986. Design Development and Deployment of Instrument Packages to Monitor the Motion of Glacial Ice Masses at Sea. Ice Technology, Proc. of 1st Int. Conf., Springer-Verlag, New York, pp. 225-236.

Lewis, C.F.M., Parrott, D.R., Lever, J.H., Josenhans, H.W., Barrie, J.V., Woodworth-Lynas, C.M.T., Diemand, D., Carter, W. and Bass, D. 1987. The Dynamics of Iceberg Grounding and Scouring (DIGS) Experiment: Engineering Implications. Proceedings of 9th Int. Conf. on Port and Ocean Engineering under Arctic Conditions, Fairbanks, Alaska.

Figure 1

Sites Investigated and Recommended Site

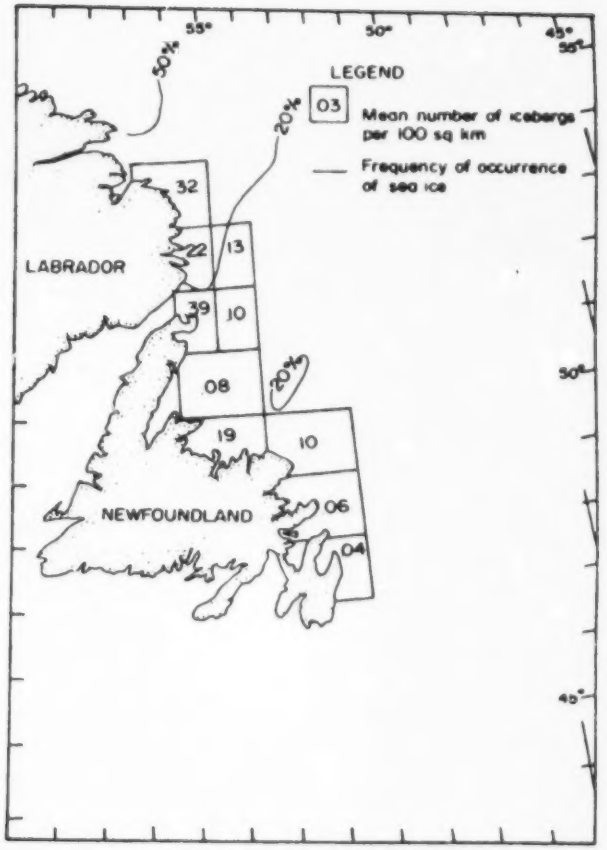

Figure 2

Iceberg Density and Sea Ice Frequency June

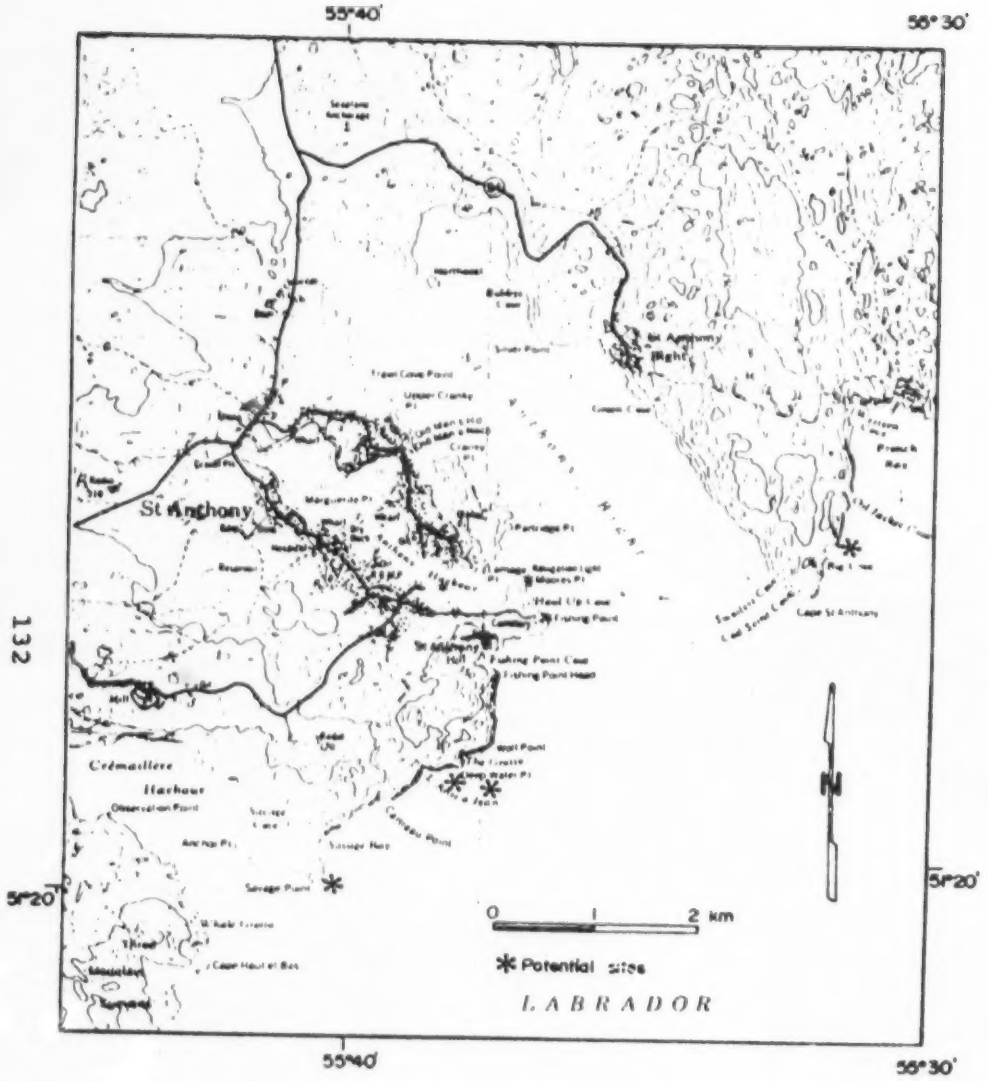

Figure 3 Topographic Maps for St. Anthony Area

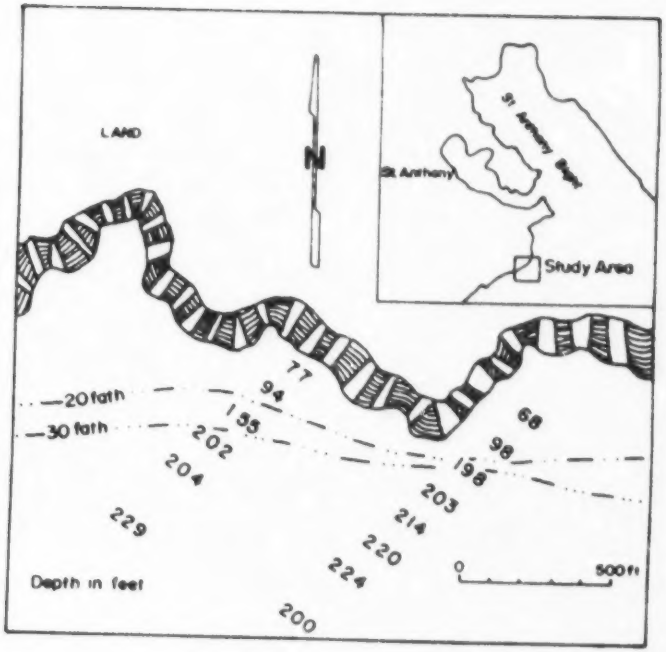

Figure 4

Section of Hydrographic Field Sheet Showing Deep Water Point Area Near St. Anthony

Figure 5 Deep Water Point, Nfld. - A Potential Site For Full Scale Iceberg Impact Test.

STUDY #8
DISCUSSION

Question: **(M. Metge)** How would you measure failure areas?

Answer: The measurement of contact area is beyond the scope of this study. There is room for imagination here. One can conceive some kind of net with ping pong balls attached to the nodes. The number of balls crushed would give an estimate of area. Also, if the geometry of the cliff and the iceberg is well delineated, above and underwater photography of the collision would give an estimate of the contact area.

Question: **(R. Frederking)** Could you put DIGS (Dynamics of Iceberg Grounding and Scouring) on the graph?

Answer: Measurements from an iceberg splitting and slamming onto the sea floor as part of C-CORE'S Dynamics of Iceberg Grounding and Scouring (DIGS) Experiment indicate a seabed-iceberg interaction pressure of 1.2 $\pm$ 0.8 MPa over a contact area of 4000 $\pm$ 1000 m^2. These estimates are obtained from side scan sonar profiling of the iceberg before it split and the acceleration of the iceberg half that slammed on the seabed. No surveying of the footprint or measurement of soil strength were attempted. Details can be found in a paper by James Lever in Offshore Mechanics and Arctic Engineering, 1989.

Question: **(J. Benoit)** What effect will improved I/B information have on the design, cost and safety of different

structures? How many impacts can be expected? Cost per data point?

Answer: Many factors influence the design of an oil producing structure in an iceberg infested region. Foremost are undoubtedly economical considerations. Of the engineering factors, one can list wave force, towing stability, seabed strength (for a gravity based structure or GBS), ice loads, etc... As far as ice is concerned, iceberg scour on flowlines (depending on the offloading method), ice floe impact or indentation (unimportant for a Hibernia GBS), wave-driven bergy bit impact (important for local loads) and iceberg impact (important for global loads) should be considered.

The proposed experiments would only provide one necessary ingredient in the computation of iceberg impact load, namely ice strength at large contact areas. They will not provide other necessary ingredients such as the impact eccentricity, the hydrodynamics of an iceberg in the vicinity of a large structure, the geometry of the structure and the iceberg. Also ice strength at large contact areas is a simplified description and comprises various modes of failure, including crushing, spalling, splitting, etc...

Although large icebergs impact much less frequently than smaller ones, they must be accounted for in the design. A structural failure which results in a great risk to life or a high risk potential for environmental pollution or damage should fall under CSA safety Class 1. For infrequent loads the code recommends designing for events with annual exceedence

probability of 10^{-4}. It is clear that large impacts must be accounted for at that level of probability. It is a good idea to perform a cost-benefit analysis of a large impact experiment in relation to a particular structure. Such a study may very well indicate, for example, that a better statistical definition of iceberg mass, velocity and geometry is more important than a refinement of iceberg strength. It may also point out that below a certain value of iceberg strength, other factors take over and govern the design.

It seems clear, however, that the proposed GBS structural shape is governed by iceberg impact. (It is interesting that, once the shape has been decided, wave loads turn out to be greater than iceberg impact load. On the other hand, the large waterline area of the proposed GBS adds to towing stability). It is conceivable that a significantly lower iceberg strength may bring about a completely different and more economical structural concept. An improved knowledge of iceberg strength at a realistic scale would also help refine the estimate of the safety of the structure.

If the proposed site and scheme are proven adequate, several impacts can be generated in one or several seasons. The data points are expensive but only represent a small portion of the cost of a GBS or an offshore well. There will not be enough points to constitute a statistical basis, but one or a few points are better than none.

Question: (S. Hotzel) Was the bottom of the site surveyed? It is unusual to have a cliff that isn't undercut by waves.

Answer: The bottom of the site was not surveyed as part of this study. This must be done if work proceeds. If the cliff is undercut by waves, its slope will be steeper underwater, and this could be an advantage, depending on the extent of the undercut. On the other hand, rubble and loose rock would be a disadvantage that may need to be removed.